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ABSTRACT

Seriation refers to the process of ordering objects along single or multiple magnitude dimensions such as length, weight, and color. The ability to order objects in terms of some attribute is essential for the child's understanding of the properties of numbers. This study investigated the effect on seriation performance of increasing both the salient features of the relevant dimension of a seriation task and the number of objects in the series, as well as the predictive value of seriation tasks on number line comprehension. The subjects were 310 children from preschool, kindergarten, and grades 1 and 2. Sixteen seriation tasks were administered along with number line comprehension tasks. The results indicated that 10 to 37 percent of the preschoolers and young kindergarten students were able to construct a correct series of tasks with 6 objects in which the relevant feature was made more salient. A sharp decrease in the seriation performance was observed for these children when the number of objects in the same seriation tasks was increased from 6 to 10. The majority of the children solved the seriation tasks with 6 objects and salient dimensions perfectly. The increase in the number of objects from 6 to 10 produced a decrease in seriation performance varying between 4 and 25 percent. In primary grade 2, all the children were able to perform the different types of seriation tasks correctly. Stepwise multiple regression analyses revealed that a selection of 6 seriation tasks (3 with 6 objects and 3 with 10 objects) predicted a multiple R = .86 for performance on the number line comprehension tasks. Adding salient features to the seriation as well as varying the number of objects provided a set of tasks suitable for investigating the development of seriation in preschoolers and kindergarten students. (Contains 26 references.) (KDFB)

On the Relation Between Seriation and Number Line Comprehension: A Validation Study

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Running Head: Seriation/Number Line Comprehension

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Abstract

This study investigated the effect on seriation performance of increasing both the salient features of the relevant dimension of a seriation task and the number of objects in the series as well as the predictive value of seriation tasks on number line comprehension. The participants, $\underline{N}$ = 310, were children from pre-school, kindergarten and primary school grades 1 and 2. The results in general showed that 10 to 37% of the pre-schoolers and young kindergartners were able to construct a correct series of tasks with six objects and in which the relevant feature was made more salient. In contrast, a sharp decrease in the seriation performance was observed for these children when the number of objects in the same seriation tasks had been increased from six to ten. The majority of the children solved the seriation tasks with six objects and salient dimensions perfectly. The increase in the number of objects from six to ten produced a decrease in the seriation performance varying between 4 and 25%. In primary school grade 2, all the children were able to perform the different types of seriation tasks correctly.

Stepwise multiple regression analysis revealed that a selection of six seriation tasks (three with six objects and three with ten objects) predicted a multiple R = .86 for the performance on the number line comprehension tasks. It was concluded that adding salient features to the seriation as well as varying the number of objects provided a set of tasks suitable for investigating the development of seriation in pre-schoolers and kindergartners.

On the Relation Between Seriation and Number Line Comprehension: A Validation Study

In the educational and the developmental psychological literature, seriation refers to the process of ordering of objects along single or multiple magnitude dimensions, e.g. length, weight, and color (Piaget & Szeminska, 1941, Brainerd, 1979). The understanding of sequential relationships permits a child to construct a logical series in which A < B < C. According to Piaget (1961) the ability to order objects in terms of some attribute is essential for the child's understanding of the properties of numbers. With the ability to handle an operation like seriation - an important thinking ability - the child develops a logical system of thinking. Research into thinking processes in general is theoretically and practically relevant, and is still given a great deal of attention (Kingma, 1986; Klauer, 1992; Tomic, Kingma & TenVergert, 1993; Tomic, 1995; Tomic & Klauer, 1995).

Previous research has shown that children's seriation performance is affected by task-variables such as the number of objects used, differences between objects and the amount of encoding load (Siegel, 1972, Kingma, 1982, Kingma & Roelinga, 1984). Encoding load is described as effects of varying the amount of information to encode of different types of tasks (Kingma, 1983). Seriation becomes more difficult when the stimuli vary on properties other than the one on which they have to be seriated. The process of encoding may be facilitated by increasing the salience of the property on which the objects are to be seriated. For example, Kingma (1982) showed with children of kindergartens and primary schools grades 1 and 2 (N = 300), that increasing the salience of the relevant dimension in a seriation task will improve the seriation performance and that decreasing the salience produces the opposite result (Kingma, 1982). Kingma and Roelinga (1984) found that the amount of encoding load strongly influenced the developmental sequences of seriation, a participant neglected in Piagetian tests (Kingma & Loth, 1985). In addition to the stimulus characteristics of a seriation task, the number of objects to be seriated can affect the seriation performance, i.e., decreasing the number of objects improves the seriation performance and increasing the number of objects evokes a decrease in the seriation performance in pre-schoolers and kindergartners (Kingma, 1982).

Kingma and Reuvekamp (1984) constructed a developmental scale for seriation consisting of both traditional seriation tasks (derived from Piaget's publications) and seriation tasks in which the amount of encoding load was varied systematically. Participants were children (N = 595) from kindergarten and primary school grades 1 and 2. They found that the performance on this developmental scale was a valid predictor (R = .80) for the performance on number line comprehension tasks, e.g., determining which number precedes 7, or whether 7 or 8 is the smaller number. In a second study in which this developmental seriation scale was used, - the participants were also children from kindergarten and primary school (N = 162) - Kingma and Loth (1985) found, using a stepwise multiple regression analysis, that a selection of two seriation tasks (seriation on length and seriation on width) explained 76.4% of the variance on the number line comprehension tasks, whereas the remaining tasks did not add significantly to the predictive validity. However, these two seriation tasks were too difficult for kindergartners. Although they may be employed for diagnostic purposes, a more refined set of seriation tasks is needed to assess the developmental level of the child's seriation ability.

Consequently, the purpose of the present study was to investigate the effect of varying both the encoding load and the number of objects on the seriation performance in young children.

Method

Participants

The participants were 310 children from two day-care centers, four kindergartens and two primary schools, grades 1 and 2 (see Table 1). The kindergartners were divided into two age levels: age level 1 (the young kindergartners) and age level 2 (the older kindergartners). The children represented a cross section of the districts' day-care and school population. Parents were informed of the nature of the study and agreed in writing to have their children participate in the study. These participants were chosen in order to compare findings with similar populations in previous seriation research (Kingma & Reuvekamp, 1984; Kingma & Loth, 1985; Kingma, 1986; Tomic & Klauer, 1996; Tomic, 1995). All groups consisted of approximately an equal number of girls and boys.

INSERT TABLE 1 ABOUT HERE

Materials

The following 16 seriation tasks were then administered (see Figure 1)

INSERT FIGURE 1 ABOUT HERE

Tasks A[1] and B[1] from Kingma and Loth (1985), seriation on length, served as a frame of reference. The number of objects to be seriated was either six or ten. (With fewer than six objects, the child may produce a correct series at random, see Kingma, 1982.)

In tasks A and A[1], a single seriation had to be performed by ordering, respectively, six and ten tubes according to increasing length. The shortest tube was 10 cm, the difference in length between the successive tubes was .5 cm.

Tasks B and B[1] seriation on length. The width of rectangles (with faces) served as an irrelevant cue making the relevant dimensions less salient. The difference in length between the successive rectangles in the series was .4 cm. The respective length and width dimensions of the ten rectangles were: 6.4 x 4.0 cm; 6.8 x 6.0 cm; 7.2 x 3.2 cm; 7.6 x 2.8 cm; 8.0 x 5.2 cm; 8.4 x 4.8 cm; 8.8 x 3.6 cm; 9.2 x 4.0 cm; 9.6 x 6.4 cm; and 10.0 x 4.4 cm.

Tasks C and C[1] seriation on length. The difference in length between the successive objects was .5 cm. The shortest measured 5.0 cm in length.

Tasks D and D[1] seriation on length. Three additional cues increased the salience of the relevant dimension: the length of a row of squares in each successive rectangle, the number of squares in a rectangle corresponding to the correct ordinal position in the series, and the total area made black by the squares in each rectangle (see Brainerd & Siegel, 1978). The dimensions of the rectangles were identical to those from tasks C and C^1.

Tasks E and E^1 seriation on length or number. (Dimensions of the rectangles: width 4.0 cm, length 10.0 cm. The black squares measured .5 x .5 cm.) Both the number of squares and the total area made black by the squares served as salient features of the relevant dimension to be seriated.

Tasks F and F^1 seriation on number. (Dimensions: the same as in tasks E and E^1.) The density of the squares as well as the area made black by the squares in the row increased the salience of the relevant dimensions. From the second rectangle in the series on, the length of the row of squares was the same for the successive rectangles.

Tasks G and G^1 seriation on number. (The rectangles and the squares have the same dimensions as those from tasks E and E^1.) The total area made black by the squares in each rectangle was a salient feature of the relevant dimension. However, the density of the squares in a row decreased as the number of squares increased. Therefore the difference between two rows may have been more difficult to perceive, i.e., the decrease in density made the (relevant) dimensions less salient.

Tasks H and H^1 seriation on number. (Same dimensions as tasks E and E^1.) In each rectangle the squares were spread out in an irregular pattern. The area made black by the squares is a salient feature of the relevant dimension.

The number line comprehension tasks consisted of three types of questions: (a) Which number follows a particular number? (i.e., 3, 7, 10, 14, 26, 38 and 59 respectively); (b) Which number precedes a particular number? (i.e., 7, 15, 25 and 43 respectively), and (c) Which number is greater or smaller? (i.e., 9 or 8, 7 or 12, 21 or 18, 43 of 39 respectively, for questions concerning "greater" and 7 or 8, 13 or 21, 49 or 51, for the questions regarding "smaller").

Scoring

A seriation task was given a score of 1 when a correct series was produced and a zero score when an incorrect series was made. A number line task received a score of 1 when the child gave a correct response, and a zero score in the case of an incorrect response.

Procedure

The children from the different participating schools were randomly assigned to five experimenters and were individually tested in an empty room where the experimenter and the child sat facing each other at a table. The two seriation tasks from Kingma and Loth's (1985) study served as a frame of reference.

Before the tasks were administered one introductory task was administered to the children so that they would become familiar with the study tasks. The introductory task contained three cardboard rectangles, each with a width of 4.5 cm. Each successive rectangle was 1 cm longer than the previous one. The shortest rectangle was 5.8 cm and the longest 7.8 cm. The experimenter demonstrated the seriation on length and following this, the child had to seriate the three rectangles.

The 16 seriation tasks were administered in two sessions: eight seriation tasks were presented in the first session, and the remaining tasks were administered in the second session. The time between sessions was one day. At the beginning of each session the two introductory tasks were presented. Following this, the seriation tasks were administered in random order. According to the concentration and motivation of the child, the duration of each test varied.

The number line comprehension tasks were administered in a third session. The three sessions (2 seriation tasks and 1 number line comprehension task) were counter-balanced for effects of practise reason. For the number line comprehension task an introductory trial was given for each type of question. The tasks were administered in random order.

Results

For each group of children p-values (proportion of correct responses, see Nunnally, 1978) were computed for all 16 seriation tasks. In order to distinguish the effects of the number of objects to be seriated, the p-values of the seriation tasks with six objects are presented separately from those tasks with ten objects.

With respect to the seriation tasks with six objects, adding an irrelevant cue to the object makes the seriation more difficult, as can be seen in Table 2. Task B (seriation on length with an irrelevant feature, i.e., width of the rectangle) appeared to produce the lowest p-values for all groups. Single seriation on length, task A, was the second most difficult seriation task for the groups, except for primary school grade 2. Adding salience cues improved the performance on the seriation tasks (D, E, F, G and H) relative to the results on the length seriation task with no salience features. The most difficult seriation tasks (A, B and C) differentiated well pre-school, kindergarten and primary school grade 1. In primary school grade 2 only ceiling effects, i.e., p-values $\geq .90$, were observed. In contrast, the seriation tasks in which the relevant feature was made more salient differentiated pre-school and kindergarten, whereas in primary school grades 1 and 2 only ceiling effects were found.

INSERT TABLE 2 ABOUT HERE

The analysis of the seriation tasks with ten objects showed that increasing the number of objects to be seriated from six to ten resulted in a sharp decrease in the seriation performance in pre-school, kindergarten and primary school grade 1 pupils. It can be seen from Table 2 that the greatest drop in the seriation performance appeared in tasks F^1 to H^1 as compared with tasks F to H. On average, all tasks with salience cues (task C^1 to H^1) produced the highest p-values in comparison with the traditional seriation task (A^1) on length (Table 2). Task B^1, containing the irrelevant feature of width, was the most difficult seriation task. The decrease in the salient feature of this task combined with an increase in the number of objects by four produced a lower performance in the kindergarten group and primary school grade 1. Seriation tasks with ten objects seemed to be too difficult for pre-school children, because seven tasks produced floor effects (p-values less than .10). Only seriation task E^1 was on the borderline (with p-value of .10) as to considering the task suitable for this age group. Turning to tasks F^1 through H^1, these tasks showed a sharper decrease in seriation performance from pre-school to primary school grade 1 than both tasks C^1 and D^1 and their counterparts with six objects from Table 2. Tasks F^1 and H^1 refer to the counting principle. The decrease in the performance on these tasks compared with those containing six objects may be attributed to the fact that young children find it easier to order six objects from one to six than to order objects when the squares (in the rectangle to be seriated) exceed the number of six.

With regard to the number line comprehension, the tasks differentiated very well pre-school through the primary school grade 1 sample (see Table 3). Ceiling effects were observed for 16 tasks in primary school grade 2, whereas in pre-school eight tasks produced a floor effect.

INSERT TABLE 3 ABOUT HERE

<u>Psychometrics</u>

To test for reliability, item-rest correlations (item-corrected total correlations) and the Kuder-Richardson homogeneity indices (KR_{20}) were computed. A $KR_{20} \geqq .80$ and item-rest correlations of $\geqq .50$ can be considered satisfactory according to Nunnally (1978). $KR_{20} = .97$ for all 16 seriation tasks (A to H and A^1 to H^1) with item-rest correlations ranging from .74 to .90. The number line comprehension tasks produced a KR_{20} = .95 and the item-rest correlations varied between .52 and .81.

Subsequently the correlation between the predictors (the seriation tasks) and the criterion variable (the total score on the number line comprehension tasks) were computed. It can be seen in Table 4 that all seriation tasks had rather high correlations with the total number line comprehension score. However, on average the correlations between the seriation tasks with six objects and the criterion variable are somewhat higher than the correlations between the seriation tasks with ten objects and the criterion variable.

INSERT TABLE 4 ABOUT HERE

Stepwise multiple regression was performed to predict which combinations of seriation tasks would improve the prediction of the performance on the number line comprehension tasks. The best prediction was found for the combination of the following six seriation tasks: D^1, A^1, G, F^1, C and E (R of .86 was found). Three tasks (D^1, A^1 and F^1) contain ten objects to be seriated, whereas the other three seriation tasks (G, C and E) have six objects.

Discussion

The extension of Kingma and Loth's (1985) original seriation tasks by either the number of objects to be seriated or by increasing the salient features proved to be a worthwhile extension to tasks that would otherwise be too difficult for pre-schoolers and kindergartners. In general, it was found that the number of objects to be seriated has a huge effect on seriation performance. To find a more refined set of seriation tasks in future research, the number of objects may be manipulated from six to more than ten. A decrease in the number of objects to below six may not be worthwhile, because with a small number of objects the child may produce a correct series at random as Piaget (1941) pointed out (see also Kingma, 1982).

Increasing the salience of the relevant dimension improved performance on the seriation tasks, especially in pre-schoolers and kindergartners. These results concur with other research in which it was found that increasing the salience of the relevant dimension influenced children's performance in problem-solving tasks (Suchman & Trabasso, 1966, Tatarsky, 1974) and in other Piagetian tasks such as conservation (Gelman, 1969, 1972; Gelman & Gellistel, 1978; Miller, 1973). The salience dimension in the present study consisted of compound dimensions: number, amount of area made black, and density of the squares. Although these aspects may be considered important from a theoretical point of view, in practice the different salience manipulations did not differentiate the groups very much. For example, tasks D to E (with six objects) had about the same p-value in pre-school and kindergarten. However, tasks F to G, in which the density cue of the number of squares did not increase proportionally with the ordinal number of the objects to be seriated, produced even small but higher p-values in pre-school and kindergarten than seriation tasks D and E, in which the increase in the density of the objects corresponds to the increase in the number of objects in the series. In contrast, the random placement of the squares in the rectangles (task H) produced a small decrease in seriation performance in pre-school and kindergarten (tasks F and G respectively). It seems that the random order of the squares affects either the ability to count the number of objects correctly (as Gilman 1969, already pointed out), or the ability to differentiate between the rectangles based on the area made black by them (Brainerd & Siegel, 1978).

In future research, the area made black by the figures within the rectangles may be held constant, e.g., the second rectangle will contain two figures that blacken the same amount of space as the figures in the first rectangle, etc. In that particular case the salience cue would focus more or less on number only.

In general, it may be concluded that seriation with ten objects is too difficult for pre-schoolers. From a developmental psychological point of view the whole set of 16 seriation tasks may be considered appropriate to study the development of seriation abilities from pre-school to grade 1 of primary school. The set of items satisfied Nunnally's criteria for reliability (both KR_{20} and item-rest correlations).

A selection of six of these 16 seriation tasks were found to predict number line comprehension ($R = .86$) even better than in earlier research, in which seriation tasks derived only from Piaget's publications produced an $R = .73$ for the number line comprehension (Kingma & Koops, 1983). In the present study, the best predictors for number line comprehension consisted of three seriation tasks with ten objects and three with six objects, whereas in another study (Kingma & Koops, 1983) on seriation tasks the number of objects varied between 10 and 25. The improvement of the predictive value may be attributed to either varying the number of objects to be seriated from six to ten or increasing the salient features of the relevant dimensions.

In future research these types of seriation task may be employed as a starting point to develop developmental scales by means of non-parametric or parametric item response models (Kingma & Van den Bos, 1988) in which the total number of 16 original tasks may be reduced, i.e., only those seriation items may be selected that do not show any overlap. Such an effect seems worthwhile since the seriation tasks are good predictors for performance in number line comprehension.

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TABLE 1

A Survey of the Number of Subjects Per Group and Their Mean Age in Years and Months (N_{total} = 310)

Participants	N	Mean Age in Years	Mean Age in Months
Pre-school children	67	4.2*	50
Kindergarten age level 1	57	4.11	59
Kindergarten Age level 2	75	5.9	69
Primary school grade 1	71	7.0	84
Primary school grade 2	40	8.5	101

*: meaning four years and two months

TABLE 2

The Proportion of Correct Solutions to Seriation Tasks With Six And Ten Objects For the Different Age Groups (N = 310)

Seriation tasks	Pre-school	Kinder-garten group 1	Kinder-garten group 2	Primary school grade 1	Primary school grade 2
	Age Group				
A. Single seriation	.03	.11	.47	.82	.98
A[1].	.02	.05	.32	.70	.88
B. Seriation on length with irrelevant cues	.01	.04	.33	.75	.98
B[1].	.00	.04	.24	.59	.90
C. Seriation on length (additional cue size)	.06	.19	.56	.89	1.00
C[1].	.05	.14	.45	.80	1.00
D. Seriation on length with three additional cues (size, length of the rows of the squares and the number of squares)	.12	.25	.69	.97	1.00
D[1].	.08	.23	.63	.93	1.00
E. Seriation on length (additional cue: length of the row of the squares)	.13	.25	.72	.96	1.00
E[1].	.10	.18	.56	.90	1.00
F. Seriation on number (squares evenly spread)	.19	.37	.75	.99	1.00
F[1].	.05	.11	.41	.87	.98
G. Seriation on number (increasing number reflects decreasing density)	.18	.37	.72	.99	1.00
G[1].	.05	.09	.47	.75	.95
H. Seriation on number (squares are randomly spread out)	.12	.30	.69	1.00	1.00
H[1].	.03	.12	.40	.82	1.00

[1]: seriation tasks with ten objects

TABLE 3

The Proportion of Correct Responses on the Number Line Comprehension Tasks From Pre-school Through Primary School Grade 2 (N = 310)

Item	Pre-school	Kinder-garten group 1	Kinder-garten group 2	Primary school grade 1	Primary school grade 2
Which number comes after					
3	.52	.65	.88	.99	1.00
7	.28	.56	.77	.98	1.00
10	.19	.31	.65	.94	1.00
14	.19	.19	.57	.94	1.00
26	.10	.07	.38	.80	1.00
38	.07	.07	.29	.78	.97
59	.00	.01	.11	.31	.88
Which number precedes					
7	.09	.16	.41	.75	1.00
15	.00	.00	.21	.59	.97
25	.00	.00	.16	.60	.95
43	.02	.02	.14	.55	.97
Which number is the greatest					
9 or 8?	.22	.30	.65	.96	1.00
17 or 12?	.19	.28	.64	.88	1.00
21 or 18?	.14	.24	.48	.63	.97
43 or 39?	.07	.17	.26	.36	.80
Which number is the smallest					
7 or 8?	.23	.50	.69	.96	1.00
13 or 21?	.20	.33	.52	.76	.95
49 or 51?	.09	.11	.20	.39	.83
$\overline{X}$	2.67	4.00	8.20	13.8	17.29
S.D.	3.15	3.13	4.74	3.79	1.74

Note: The maximum score is 18.

TABLE 4
The Correlations of the Predictors (the Seriation Tasks) With Number Line Comprehension Task For Pre-school Through Primary School Grade 2 Children (N = 310)

Predictors Seriation Task	Criterion Variable Number Line Comprehension
Six Objects	**R**
1. A. Single seriation on length	.68
3. B. Single seriation on length with irrelevant cues	.69
5. C. Seriation on length (additional cue size)	.73
7. D. Seriation length with three additional cues	.70
9. E. Seriation on length (additional cue number)	.73
11. F. Seriation on number (squares evenly spread)	.70
13. G. Seriation on number (increasing number reflects decreasing density)	.71
15. H. Seriation on number (squares are randomly spread out)	.72
Ten Objects	**R**
2. A^1. Single seriation on length	.71
4. B^1. Seriation on length with irrelevant cues	.63
6. C^1. Seriation on length (additional cue size)	.71
8. D^1. Seriation on length with three additional cues	.74
10. E^1. Seriation on length (additional cue is number)	.72
12. F^1. Seriation on number (squares evenly spread)	.68
14. G^1. Seriation on number (increasing number reflects decreasing density)	.66
16. H^1. Seriation on number (squares are randomly spread out)	.69

Figure Capture

Figure 1 A Survey of the seriation Tasks

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